Understanding the Interactions between Wildfire Disturbance, Landscape Hydrology and Post-Fire Recovery in Boreal-Taiga Ecosystems

PI: Laura L. Bourgeau-Chavez[1];

Nancy HF French[1], Michael Battaglia[1], Michael Billmire[1], Evan Kane[1], Jacquelyn Shuman[2], Sean Swenson[2], Paul Siqueira[3], Bruch Chapman[4], Chelene Hanes[5], Alan Cantin[5], Ellen Whitman[5], Mike Flannigan[6], Aaron Berg[7], Adrianna Foster[8], Jennifer Baltzer[9]

[1]Michigan Technological University, [2]NCAR, [3]University of Massachusetts, [4]NASA JPL, [5]Natural Resources Canada Canadian Forest Service, [6]University of Alberta, [7]University of Guelph, [8]NASA Goddard SFC, [9]Wilfred Laurier

Project Summary & Background

Goal: Improve our understanding of the interactions of wildfire and hydrology (including permafrost changes) and the ensuing post-fire successional trajectories in both uplands and peatlands of the Artic-Boreal Zone (ABZ) in a changing climate.

- Hydrology is an important component of wildfire vulnerability and post-fire successional trajectories. Under this project we will pursue the development of effective microwave soil moisture retrieval algorithms from satellite and airborne systems, from field to regional scales.
- To better understand, diagnose and predict ecosystem dynamics, especially the interaction of hydrology with wildfire and post-fire recovery, integration of field and remote sensing data observations with a landscape scale ecosystem model coupled to a hydrological model is needed.

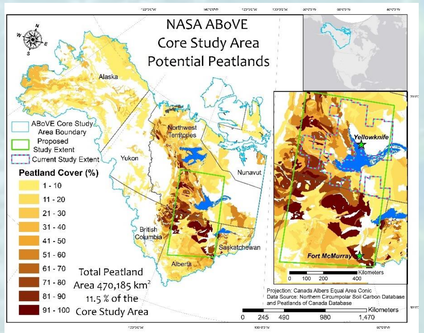


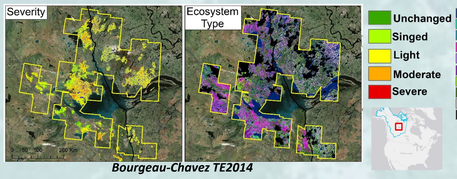
Figure 1. Percent Cover of Peatlands across the NASA ABoVE Core Study area based on Hugelius' soil database (Schuur et al. 2015), using mapped areas of Histel (permafrost organic soils) and Histosol (unfrozen organic soils) to estimate peatland area. Tarnocai's (2006) peatland map of Canada was used to fill in a data gap for the southeastern most portion.

Project will focus on the intensive study of the 2014-2016 wildfires in southern Northwest Territory (NWT) and northern Alberta where peatlands are abundant (Fig 1).

This project continues the work of Phase I ABoVE grant (#NNX15AT83A, Bourgeau-Chavez TE 2014), leveraging the remote sensing and field data collected under the previous grant to lay the foundations for fire effects modeling.

Field and Remote Sensing Data for Model Parameterization/Validation

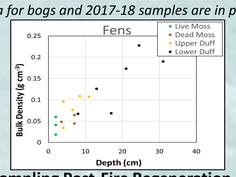
Organic Soil Burn Severity and Peatland/Upland Ecotype Map



Bourgeau-Chavez TE2014

Organic Soil Fuel Loading Measurements

Field data on peat bulk density by depth for Fens. *Data for bogs and 2017-18 samples are in process.*



152 Field Sites Under Investigation (85 burned – 67 unburned)

		Ecozone			
		Taiga Plain	Taiga Shield	Boreal Plain	SUM
Ecosystem	Open/Shrub Fen	18 (9)	3 (2)	0	21
	Treed Fen	24 (14)	17 (11)	0	41
	Bog	38 (21)	21 (10)	3 (2)	62
	Lowland Conifer	5 (4)	5 (5)	0	10
	Lowland Deciduous	5 (0)	0	0	5
	Upland	7 (4)	4 (3)	0	11
	Marsh	1(0)	1 (0)	0	2
	SUM	98 (52)	51 (31)	3 (2)	152 (85)

Summary of Field Data Sites in each ecotype/ecozone. Totals are shown and value in ( ) are # burned. Each site is 1 ha subsampled in 6 10m x 10m plots along 2 transects

Sampling Post-Fire Regeneration

- Field data will be used in parameterization-validation of FATES, CLM-HH and CanFIRE models
- Post-fire regeneration and soil moisture will continue to be sampled coincident with SAR overpasses (R-2 and UAVSAR) at burn sites in 2019-2020
- Soil moisture and biomass will be sampled in unburned sites for SAR moisture retrieval model development – see next panel

SAR Retrieval of Field Scale Soil Moisture

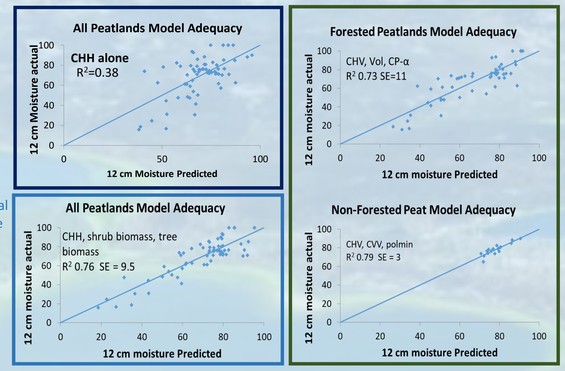
Objective 1: Develop algorithms for soil moisture retrieval from the Arctic Boreal Zone using L-band UAVSAR in preparation for NASA's NISAR mission and investigate the frequency limitations (L-, C- and P-band SAR) in boreal systems. A useful corollary is to gauge the effect of soil moisture changes on estimates of aboveground biomass.

Hypothesis: *Fully polarimetric data will benefit soil moisture retrieval by providing information on vegetation structure and biomass*

Pre-Fire Peatland Soil Moisture Retrieval Preliminary Results C-band

C-band single channel backscatter is related to soil moisture, but variations in biomass and surface roughess cause uncertainty in retrieval

Retrieval with actual field measured tree and shrub biomass in the algorithm shows model adequacy we are hoping to match with SAR polarimetry (plots on right).

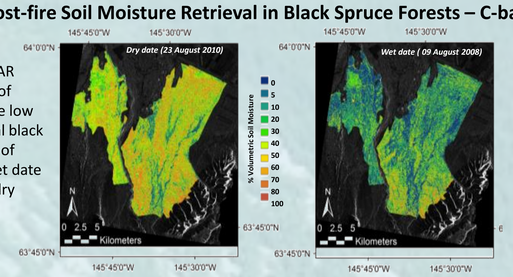


Producing SAR polarimetric algorithms for forested and non-forested peatlands separately provides model accuracies approaching those of the model with actual tree and shrub biomass at left (bottom).

Plots of C-band HH, HV, and VV polarization scatter in predicted vs. actual moisture plots. Top left: Includes all treed fens, wooded bogs, shrubby fens, and open fens sites from Alaska, Alberta CA, and Michigan's UP. Bottom left: Addition of shrub and treed biomass increases model prediction and helps account for scatter variability. Note R^2 without shrub was merely 0.46, shrub biomass and tree biomass (0.76). Top right: C-band polarimetric parameters and CHV backscatter produce a good fitting model for forested peatlands. Bottom right: C-band HV and VV scatter with the minimum degree of polarization provides the best fit for all non-forested peatlands.

Post-fire Soil Moisture Retrieval in Black Spruce Forests – C-band

Polarimetric SAR derived maps of moisture in the low biomass boreal black spruce forests of Alaska on a wet date (right), and a dry date (left).



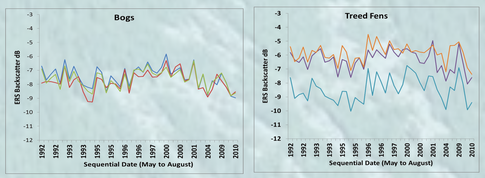
Previous work in Alaska led to soil moisture retrieval algorithms for regenerating black spruce forests. **Algorithm: %VMC = 319.31 Dmax -612.50 Unpolmax + 5190.4 CVH -266.37 R^2 = 0.77 Bourgeau-Chavez et al. 2013 RMSE 6.7%.** These algorithms will be refined with NWT/Alberta field data.

Planned Multi-Frequency Analysis :

- C-band moisture retrieval is limited to forests with biomass < 3 kg/m^2
- Analysis of L-band UAVSAR including in situ soil moisture and biomass to increase moisture retrieval capability to higher biomass sites (prior to airborne campaign L-band data was limited in this region)
- SAR polarimetry will provide information on frequency limitations due to vegetation structure & biomass and inform more widely available dual band SAR systems

Historical SAR:

Map pre- and post-fire moisture conditions across space and time using archival L- and C-band SAR datasets to provide insight into the drivers of wildfires



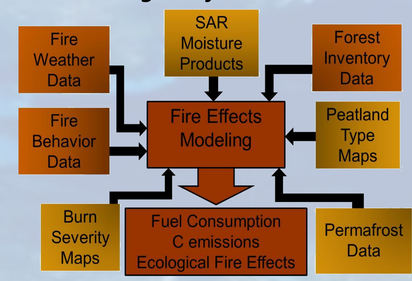
Plots of ERS backscatter over time from bogs (left) and treed fens (right). Line color corresponds to different study areas. Bogs have consistent trends in moisture (both magnitude and variance) while fens are quite variable in magnitude of backscatter over time and between fens (likely cause by high variance in hydrological status).

Modeling Post-Fire Ecosystem Processes

Objective 2: Calibrate & validate ecosystem, hydrology and fire effects models (FATES, CLM-HH, and CanFIRE) for lowlands (peatlands) and uplands.

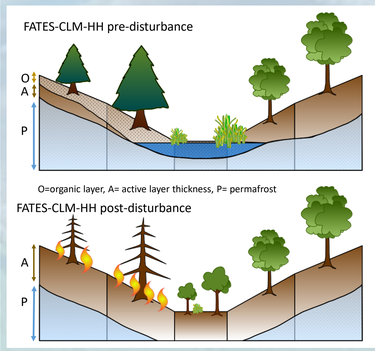
Obj. 2a) Integrate the 2015-2018 remote sensing and field collected data in a geospatial CanFIRE model.

Orange Boxes are existing inputs to CanFIRE based on the Canadian Forest Fire Danger Rating System (CFFDRS). Yellow Boxes represent remote sensing and in-situ products developed in the ABoVE Phase 1 project to assess fire effects and C emissions in boreal-taiga landscapes. Other static inputs such as topography and soil type are also used



CanFIRE: Canadian Fire Effects Model (**CanFIRE**), semi-empirical science-management integration model used to simulate physical and ecological fire effects (de Groot et al., 2002).

Obj. 2b) Integrate FATES and CLM-HH to improve understanding of the interactions between wildfire and hydrology on carbon emissions, post-fire successional trends, and conduct projections based on expected future climate scenarios.



(Left) FATES-CLM-HH simulates vegetation and permafrost response to site, climate and fire drivers. FATES represents the size-structure of plants and explicitly simulates reproduction, growth and mortality. FATES uses SPITFIRE to quantify ignition, fire behavior and plant mortality in response to fuel states and loads. CLM-HH represents sub-grid heterogeneity in hydrology by using multiple hillslopes linked via lateral transport of saturated subsurface runoff. Following fire disturbance and combustion of the organic layer, active layer depth increases, promoting drying and allowing establishment of trees in previously water-logged areas.

Hypothesis 1*: FATES-CLM-HH will capture observed trends and variability in vegetation distribution and moisture dynamics improving our mechanistic knowledge of changes in hydrology with respect to fire effects and regeneration.*

Hypothesis 2*: Hydrologically isolated bogs are more likely to be susceptible to burning, and more vulnerable to deeper burning in future climates. In contrast, fen ecosystems with groundwater connectivity will be more resilient to fire effects in terms of vegetation recovery and permafrost maintenance.*

Project Significance

- Support NASA's NISAR mission in the low biomass, hydrologically active region of the ABoVE domain by analyzing UAVSAR data collected during the 2017-18 ABoVE Airborne Campaign (AAC).
- Map soil moisture at the field scale to aid in our modeling of fire effects and post-fire regeneration, currently a data gap.
- Integrate research results from ABoVE into a coherent modeling framework to diagnose and predict ecosystem dynamics.
- Quantify C-consumption and emissions from peatlands.